Limnol. Oceanogr.: Methods 7, 2009

Quantifying phosphorus uptake using pulse and steady-state approaches in streams

Stephen M. Powers, Emily H. Stanley, and Noah R. Lottig
Center for Limnology, University of Wisconsin-Madison, Madison, WI, USA

Appendix 1: Sorption considerations and alternative model selection

Long tails in the soluble reactive phosphorus (SRP) time series for nutrient pulses in West Branch Boulder Creek (W) and the upper reach of Lower Creek ($L_{1–2}$) suggested a release of sorbed experimental P. In these cases, we used the Akaike information criterion (AIC_c; Akaike 1974) to compare simulated transport from a first-order uptake model with simulated transport from models that included a sorption algorithm. AIC_c compares the relative success of multiple candidate models and penalizes overfitting of models to observations. It is defined as

$$AIC_c = 2k + n[\ln(\frac{2\pi RSS}{n}) + 1] + \frac{2k(k+1)}{n-k-1} \quad (1)$$

where *RSS* is residual sum of squares, *n* is number of observations, and *k* is number of parameters.

In a one-dimensional transport with inflow and storage (OTIS) solute transport model, K_d sorption of SRP to sediments in the main channel (*A*) may be modeled with three additional parameters: K_d (distribution coefficient, or partition coefficient, $L^3 M^{-1}$), ρ (mass of accessible sediment per volume of water, $M L^{-3}$), and $\hat{\lambda}$ (main channel sorption rate coefficient, T^{-1}); see Bencala (1983). K_d is defined as

$$K_d = \frac{P_{sed}}{P_{sol}} \quad (2)$$

where P_{sed} is mass of P in sediment:mass of sediment and P_{sol} is concentration of SRP in solution. To employ the sorption algorithm, Bencala (1983) suggests fitting ρ and $\hat{\lambda}$ to solute observations using a fixed K_d.

Substrata and sediment P characteristics for W were reported in Lottig and Stanley (2007) and used to estimate K_d for this stream; substrata were 89.1% sand, 5.9% gravel, 1.1% silt, and 0.6% organic material; NaOH-extractable P was available for sand (11.6 µg g^{-1}) and gravel (1.3 µg g^{-1}). Weighted to % sand and gravel, we used this information to estimate P_{sed} = 10.4 µg g^{-1}. We next assumed P_{sol} = background SRP (52 µg L^{-1}, from Table 2), yielding K_d = 200 L kg^{-1}. We then evaluated multiple candidate models of SRP processing in W using OTIS, AIC_c, and the estimated value for K_d. Candidates included models with first-order uptake only (U model; λ = fitted), sorption only (S model; λ = 0, K_d = fixed, ρ = fitted, $\hat{\lambda}$ = fitted), and uptake + sorption (U+S model; λ = fitted, K_d = fixed, ρ = fitted, $\hat{\lambda}$ = fitted), all restricted to the main channel (*A*). Fitted transport parameters, RSS, and AIC_c for candidate models are reported in Table 3. For W, the S and U+S models yielded equivalent AIC_c values that were substantially favorable to the U model (AIC_U = –192.6 compared to AIC_S = –214.3 and AIC_{U+S} = –214.4; lower AIC indicates improved model success). We selected the U+S model because it accounted for likely biological assimilation of P with first-order uptake and used the fitted value of λ from this model to calculate nutrient uptake metrics reported in Table 2 and Fig. 5. Figure 1A below shows solute time series from these contrasting SRP simulations for W.

Sediment P values for $L_{1–2}$ (Fig. 3) were not available, so we bounded an estimate of P_{sed} as 5–20 µg g^{-1} and estimated P_{sol} = background SRP (33 µg L^{-1}), yielding K_{d1} = 110 L kg^{-1} and K_{d2} = 440 L kg^{-1}. K_{d1} and K_{d2} were then fixed in two separate runs of the S model (S_1 and S_2) in OTIS, yielding two different fitted values for ρ, but identical simulated solute values in each case. Parameters from the U+S model could not be fitted simultaneously (high uncertainty, too many parameters). Using AIC_c, we selected models S_1 and S_2 (λ = 0, no uptake) for calculating $L_{1–2}$ nutrient uptake metrics shown in Table 2 and Fig. 5. Thus, we demonstrate the ability of dynamic (time series) transport models to estimate the relative importance of competing nutrient processing mechanisms in lotic ecosystems.

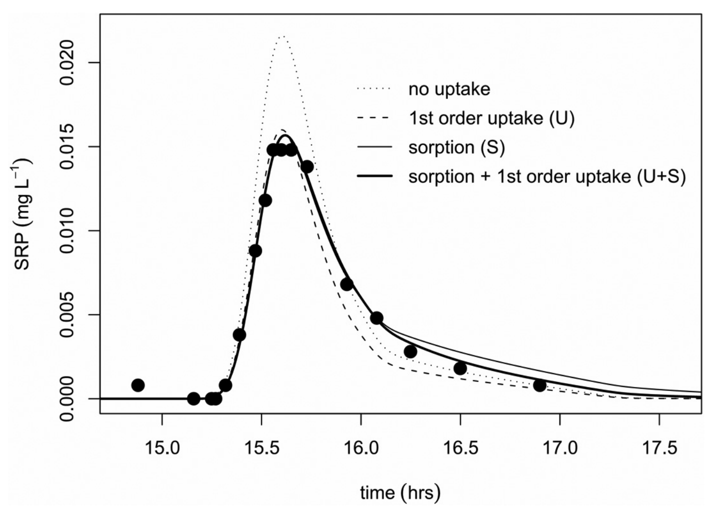

Fig. 1A. SRP pulse observations and simulations from multiple candidate models for West Branch Boulder Creek (W), Wisconsin. First-order uptake + sorption (U + S) and sorption only (S) yielded simulations that were nearly equivalent in success as measured by Akaike information criterion (AIC_c). Time is hour of day.

References

Akaike, H. 1974. New look at statistical-model identification. IEEE Transact. Auto. Control Ac 19:716-723.

Bencala, K. E. 1983. Simulation of solute transport in a mountain pool-and-riffle stream with a kinetic mass-transfer model for sorption. Water Resourc. Res. 19:732-738.

Lottig, N. R., and E. H. Stanley. 2007. Benthic sediment influence on dissolved phosphorus concentrations in a headwater stream. Biogeochemistry 84:297-309.